$B \to$ Baryon decays in Belle

S.-W. Lin
Physics Department, National Taiwan University, Taipei 106, Taiwan

We report recent observations of baryonic B decays with charmless and charmed baryons in the final state. We show the angular distributions of the di-baryon low-mass enhancements in the charmless three-body baryonic B decays and the branching fractions of B decays with two charmed baryons or charmonium in the final states. We also report the observation of the decay $\eta_c \to \Lambda\bar{\Lambda}$ at Belle.

1 Introduction

Observations of several baryonic B decays have been reported by Belle. The measured branching fractions for charmless and charmed baryonic B decays are shown in Fig. 1. In the charmless final states, only the three-body decays have been observed[1,2,3,4,5]. In this contribution, we report on the angular distribution of the di-baryon low-mass enhancements seen in the charmless three-body baryonic B decays. The data support the quark fragmentation interpretation, while the gluonic resonance picture is disfavored. In the charmed final states, we observed the two-body and three-body decays with two charmed baryons or charmonium. From the latter we can extract the branching fractions of η_c into baryon pairs $p\bar{p}$ and - for the first time - into $\Lambda\bar{\Lambda}$. Measuring decay rates of η_c to different di-baryon modes is a very useful check for theoretical predictions[6] and can shed light on quark-diquark dynamics. The data sample was collected with Belle detector at the KEKB asymmetric-energy e^+e^-(3.5 GeV on 8.0 GeV) collider[7]. KEKB operates at the $\Upsilon(4S)$ resonance ($\sqrt{s}$ = 10.58 GeV) with a peak luminosity that has exceeded 1.5 $\times 10^{34}$ cm^{-2}s^{-1}.

2 Charmless baryonic B decays

Observations of several charmless baryonic B decays have been reported at Belle. One common feature of these observations is the peaking of the di-baryon mass spectra toward threshold.

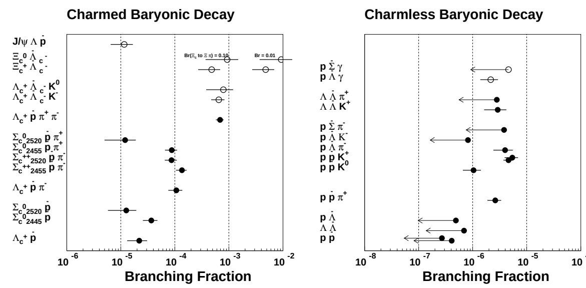

Figure 1: Branching fractions for charmless and charmed baryonic B decays. The open circles indicate new measurements from Belle.

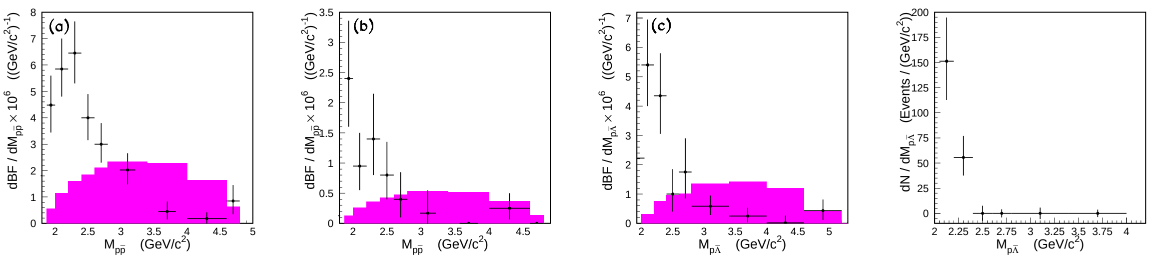

Figure 2: Differential branching fraction for (a) $p\bar{p}K^+$, (b) $p\bar{p}K^0_S$, (c) $p\bar{\Lambda}\pi^-$ and (d) $p\bar{\Lambda}\gamma$ modes as a function of di-baryon pair mass. The shaded distribution shows the expectation from a phase-space MC simulation with area scaled to the signal yield. A charmonium veto has been applied in (a) and (b).

We first measured the differential branching fractions for (a)$B^+ \to p\bar{p}K^+$, (b)$B^0 \to p\bar{p}K^0_S$, (c)$B^0 \to p\bar{\Lambda}\pi^-$ and (d)$B^+ \to p\bar{\Lambda}\gamma$ modes. There are two kinematic variables in the center of mass frame which are usually used to extract the B candidates: the beam energy constrained mass $M_{\rm bc} = \sqrt{E_{\rm beam} - p_B^2}$, and the energy difference $\Delta E = E_B - E_{\rm beam}$, where $E_{\rm beam}$ is the beam energy, and p_B and E_B are the momentum and energy of B candidates. B signal yield is obtained by a 2D fit to the ($M_{\rm bc}$,ΔE) distribution for each bin of di-baryon invariant mass. The efficiency as a function of the di-baryon mass is based on the MC simulation. The differential branching fraction for each bin in the di-baryon mass is obtained from the fitted B yield and the signal efficiency (Fig. 2). The branching fraction is a sum of the differential branching fractions[4,5].

The angular distribution of the proton is studied in the di-baryon system. Fig. 3 shows the angular distributions for the four decay channels. The angle θ_p is defined for (a) as the angle between the directions of $\bar{p}$ and K^+ in the $p\bar{p}$ rest frame. There is a clear forward peak and the angular asymmetry, defined as

$$A = \frac{N_+ - N_-}{N_+ + N_-} \tag{1}$$

where N_+ and N_- stand for the efficiency corrected B yield with $\cos\theta_p > 0$ and $\cos\theta_p < 0$, respectively, amounts to $0.59^{+0.08}_{-0.07}$ for the $p\bar{p}K^+$ mode. The asymmetry of the distribution indicates that the fragmentation picture is favored. Antiprotons are emitted along the K^+ direction most of the time, which can be explained by a parent $\bar{b} \to \bar{s}$ penguin transition followed by $\bar{s}u$ fragmentation into the final state. The $\cos\theta_p$ distribution for (b) is flat, but we have to note that in this case the statistics is low and K^0_S carries no flavor information. If in (c) we choose the θ_p angle of p with respect to the π^- in the rest frame of the $\bar{\Lambda}p$ system, the $\cos\theta_p$ distribution is quite flat. However, the $\cos\theta_p$ shows a forward peak structure if the angle is defined as the p direction relative to the $\bar{\Lambda}$ direction in the $p\pi^-$ rest frame. It is evident that the fragmentation interpretation is supported: the proton tends to emerge parallel to the

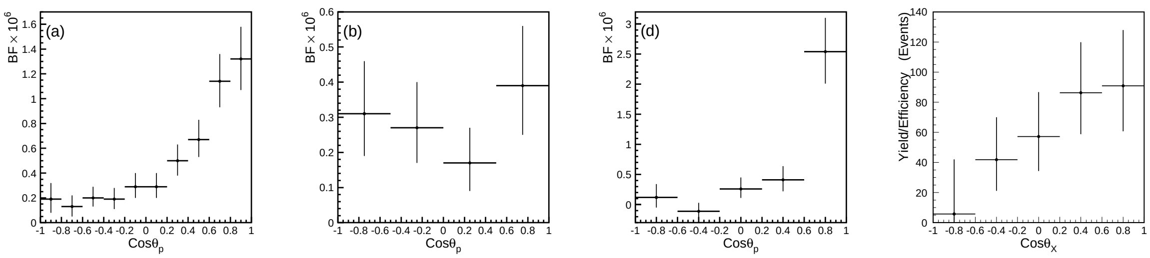

Figure 3: Branching fraction vs. $\cos\theta_p$ in the di-baryon system for (a) $p\bar{p}K^+$, (b) $p\bar{p}K^0_S$, (c) $p\bar{\Lambda}\pi^-$ and (d) $p\bar{\Lambda}\gamma$.

$\bar{\Lambda}$ baryon. The angle θ_X of (d) is measured between the proton direction and the γ direction in the baryon pair rest frame. There is also a clear forward structure in the $\cos\theta_X$ distribution and the angular asymmetry A is $0.36^{+0.23}_{-0.20}$. This distribution supports the $b \to s\gamma$ fragmentation picture where the Λ tends to emerge opposite to the direction of the photon[5].

3 Charmed baryonic B decays

In the $B^{+/0} \to \bar{\Xi}_c^{0/-}\Lambda_c^+$ analysis[8], we reconstruct the following decay modes: $\Xi_c^0 \to \Xi^-\pi^+$ and $\Lambda K^-\pi^+$, $\Xi_c^+ \to \Xi^-\pi^+\pi^+$, $\Lambda_c^+ \to pK^-\pi^+$, $\Xi^- \to \Lambda\pi^-$ and $\Lambda \to p\pi^-$. We use a simultaneous two-dimensional binned maximum likelihood fit to the ΔE vs. $M_{\rm bc}$ distributions (for the two Ξ_c^0 channels) with a common value of $\mathcal{B}(B^+ \to \bar{\Xi}_c^0\Lambda_c^+)\times\mathcal{B}(\bar{\Xi}_c^0 \to \bar{\Xi}^+\pi^-)\times\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)$. For this fit, we constrain the ratio $\mathcal{B}(\Xi_c^0 \to \Lambda K^-\pi^+)/\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+)$ to the recent Belle measurement[10] of $1.07\pm0.12\pm0.07$. The fit gives the product of branching fractions of $\mathcal{B}(B^+ \to \bar{\Xi}_c^0\Lambda_c^+)\times\mathcal{B}(\bar{\Xi}_c^0 \to \bar{\Xi}^+\pi^-)$ with the value of $4.8\ ^{+1.0}_{-0.9} \pm 1.1 \pm 1.2$ and a statistical significance of $8.7\ \sigma$. We also check the $B^0 \to \bar{\Xi}_c^-\Lambda_c^+$ mode which is an isospin partner of the $B^+ \to \bar{\Xi}_c^0\Lambda_c^+$ mode. The product of branching fraction of $\mathcal{B}(B^0 \to \bar{\Xi}_c^-\Lambda_c^+)\times\mathcal{B}(\bar{\Xi}_c^- \to \bar{\Xi}^+\pi^-\pi^-)$ is measured to be $(9.3^{+3.7}_{-2.8}\pm1.9\pm2.4)$ $\times10^{-5}$. The uncertainties in the products of branching ratios are statistical, systematic and the uncertainty from the $\Lambda_c^+ \to pK^-\pi^+$ branching fraction.

The $B^+ \to \Lambda_c^+\Lambda_c^-K^+$ and $B^0 \to \Lambda_c^+\Lambda_c^-K^0$ decays are three-body decays that proceed via a $b \to c\bar{c}s$ transition. We detect the Λ_c^+ via the $\Lambda_c^+ \to pK^-\pi^+$, $p\bar{K}^0$ and $\Lambda\pi^+$ decay channels. When a Λ_c^+ and Λ_c^- are combined as B decay daughters, at least one of $\Lambda_c^\pm$ is required to have been reconstructed via the $pK^\mp\pi^\pm$ decay process. Here, the parameter mass difference ΔM_B is used instead of the energy difference ΔE, since ΔE shows a correlation with $M_{\rm bc}$. The mass difference is defined as $\Delta M_B \equiv M(B) - m_B$, where $M(B)$ is the reconstructed mass of the B candidate and m_B is the world average B meson mass. Fig. 4 shows ΔM_B and $M_{\rm bc}$ projections for $B^+ \to \Lambda_c^+\Lambda_c^-K^+$ and $B^0 \to \Lambda_c^+\Lambda_c^-K^0$ decays. A two-dimensional binned maximum likelihood fit is performed to determine the signal yield. From the fit we obtain signal yields of $48.5^{+7.5}_{-6.8}$ and $10.5^{+3.8}_{-3.1}$ events with statistical significances of $15.4\ \sigma$ and $6.6\ \sigma$, for $B^+ \to \Lambda_c^+\Lambda_c^-K^+$ and $B^0 \to \Lambda_c^+\Lambda_c^-K^0$, respectively. Hence, we obtain the branching fractions of[9]

$$
\begin{aligned}
\mathcal{B}(B^+ \to \Lambda_c^+\Lambda_c^-K^+) &= (6.5^{+1.0}_{-0.9} \pm 1.1 \pm 3.4) \times 10^{-4} \\
\mathcal{B}(B^0 \to \Lambda_c^+\Lambda_c^-K^0) &= (7.9^{+2.9}_{-2.3} \pm 1.2 \pm 4.1) \times 10^{-4}
\end{aligned}
$$

where the first and the second errors are statistical and systematic, respectively. The last error is due to the 52 % uncertainty in the absolute branching fraction, $\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)$.

We study two-body baryonic decays of charmonia in the B meson decays, $B^+ \to p\bar{p}K^+$ and $B^+ \to \Lambda\bar{\Lambda}K^+$. The B signal yields are obtained from 10 MeV/c^2 wide $M_{p\bar{p}}(M_{\Lambda\bar{\Lambda}})$ mass bins from the kinematic threshold to 4.5 GeV/c^2. The results of η_c are the mass of $\mathrm{M}_{\eta_c} = 2.971 \pm 0.003^{+0.002}_{-0.001}$ GeV/c^2($2.974\pm0.007^{+0.002}_{-0.001}$ GeV/c^2) and the width of $\Gamma(\eta_c) = 48^{+8}_{-7} \pm 5$

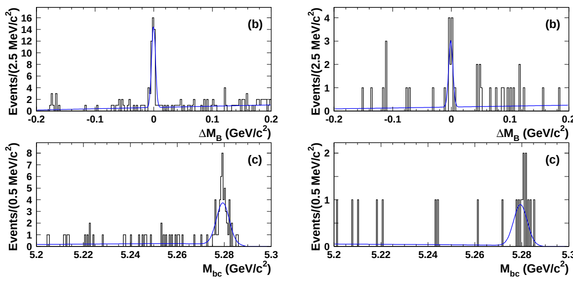

Figure 4: Candidate (a,b) $B^+ \to \Lambda_c^+ \Lambda_c^- K^+$ and (c,d) $B^0 \to \Lambda_c^+ \Lambda_c^- K^0$ decay events: (a,c) ΔM_B distribution for $M_{\rm bc} > 5.27$ GeV/c^2 and (b,d) $M_{\rm bc}$ distribution for $|\Delta M_B| < 0.015$ GeV/c^2. Curves indicate the fit results.

Table 1: Measured Branching Fractions $\mathcal{B}(J/\psi, \eta_c \to p\bar{p}, \Lambda\bar{\Lambda})$.

Modes	Yield	Efficiency(%)	$\mathcal{B}(J/\psi, \eta_c \to p\bar{p}, \Lambda\bar{\Lambda}) \times 10^{-3}$
$B^+ \to \eta_c K^+, \eta_c \to p\bar{p}$	$195.1^{+15.7}_{-14.7}$	35.8± 0.3	$1.58 \pm 0.12\ ^{+0.18}_{-0.22} \pm 0.47$
$B^+ \to \eta_c K^+, \eta_c \to \Lambda\bar{\Lambda}$	$19.5^{+5.2}_{-4.5}$	5.3 ± 0.1	$0.87^{+0.24+0.09}_{-0.21-0.14} \pm 0.27$
$B^+ \to J/\psi K^+, J/\psi \to p\bar{p}$	$317.2^{+19.0}_{-18.0}$	37.3 ±0.4	$2.21 \pm 0.13 \pm 0.31 \pm 0.10$
$B^+ \to J/\psi K^+, J/\psi \to \Lambda\bar{\Lambda}$	$45.9^{+7.7}_{-6.7}$	5.9± 0.3	$2.00^{+0.34}_{-0.29} \pm 0.34 \pm 0.08$

MeV/c^2(40± 19 ± 5 MeV/c^2) from $\eta_c \to p\bar{p}(\eta_c \to \Lambda\bar{\Lambda})$ mode. We define the η_c signal region as 2.940 GeV/c$^2 < M_{\Lambda\bar{\Lambda}} <$ 3.020 GeV/c^2. The fitted B signal yield, efficiency and branching fraction are shown in Table 1. In this study the decay $\eta_c \to \Lambda\bar{\Lambda}$ has been observed for the first time, with $\mathcal{B}(\eta_c \to \Lambda\bar{\Lambda}) = (0.87^{+0.24+0.09}_{-0.21-0.14} \pm 0.27) \times 10^{-3}$. The observed $\mathcal{B}(\eta_c \to \Lambda\bar{\Lambda})/\mathcal{B}(\eta_c \to p\bar{p})$ is $0.67^{+0.19}_{-0.16} \pm 0.12$ which is consistent with theoretical expectation[6]. We define the J/ψ signal region as 3.075 GeV/c$^2 < M_{p\bar{p}}(M_{\Lambda\bar{\Lambda}}) <$ 3.117 GeV/c^2 and use events in this signal region to study the proton angular distribution in the helicity frame of the J/ψ. The helicity angle θ_X is defined as the angle between the proton flight direction and the direction opposite to the flight of the kaon in the J/ψ rest frame. The angular distribution of the kaon direction in the J/ψ rest frame is parameterized as $P(\alpha_B, \cos\theta_X) = (1 + \alpha_B \cos^2\theta_X)/(2 + 2\alpha_B/3)$ with $\alpha_B = (-2\alpha)/(\alpha + 1)$. We determine[11] α_B to be -0.60 ± 0.13 ± 0.14 ($p\bar{p}$) and -0.44 ± 0.51 ± 0.31 ($\Lambda\bar{\Lambda}$.

References

1. Belle Collaboration, M.-Z. Wang *et al.*, Phys. Rev. Lett. **90**, 201802(2003).
2. Belle Collaboration, M.-Z. Wang *et al.*, Phys. Rev. Lett. **92**, 131801(2004).
3. Belle Collaboration, Y.-J. Lee, M.-Z. Wang *et al.*, Phys. Rev. Lett. **93**, 211801 (2004).
4. Belle Collaboration, M.-Z. Wang *et al.*, Phys. Lett. B **617**, 141(2005).
5. Belle Collaboration, Y.-J. Lee, M.-Z. Wang *et al.*, Phys. Rev. Lett. **95**, 061802(2005).
6. M. Anselmino, F. Caruso, S. Forte and B. Pire, Phys. Rev. D **38**, 3516 (1988).
7. S. Kurokawa and E. Kikutani, Nucl. Instrum. Methods Phys. Res. A**499**, 1(2003).
8. Belle Collaboration, R. Chistov *et al.*, hep-ex/0510074.
9. Belle Collaboration, N. Gabyshev *et al.*, hep-ex/0508015.
10. Belle Collaboration, T. Lesiak *et al.*, Phys. Lett. B **605**, 237 (2005), Erratum **617**, 198 (2005).
11. F. Murgia and M. Melis, Phys. Rev. D **51**, 3487 (1995).